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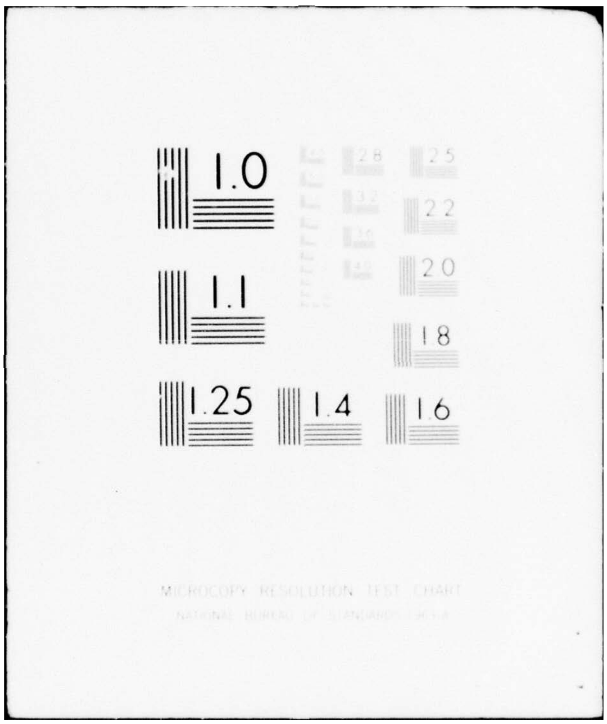
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NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

BIOFOULING ORGANISMS
AND THEIR SALINITY TOLERANCE
ON NAVIGATIONAL BUOYS
IN UPPER SAN FRANCISCO BAY

by

Dale Layne Thompson

September 1977

Thesis Advisor: E. C. Haderlie

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The navigational buoys situated along the main shipping channel of San Francisco Bay's upper portions - through San Pablo and Suisun Bays - provide biofouling surfaces of constant depth with known maintenance histories and fixed locations through a mean salinity range of 4 to 24 parts per thousand (ppt). Investigation of the biofoulers of these buoys indicates the typical communities and which species are salinity constrained in range and by what salinity. Twelve sets of samples were taken, each consisting

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of the surface scrapings of two 929 square centimeter (cm) (one square foot) areas, one with its top margin at the mean waterline, the other with its upper margin at the 61 cm depth level. This was done (with a few exceptions) resulting in 23 individual samples being obtained with 41 species identified and 48,376 individual organisms counted. San Pablo Bay's dominant biofouler is the mussel *Mytilus edulis* growing in heavy colonies with worms, amphipods, tunicates, and bryozoans. Suisun Bay's biofouling growth is of three parts - algal from the surface to 15 cm depth, a low biomass of barnacles and amphipods to a depth of 61 cm; and thereafter the erect bryozoan *Membranipora perfragilis* dominates. In San Pablo Bay, the barnacle *Balanus crenatus* is replaced by *Balanus improvisus* at salinities of less than 21 ppt. Some less well defined salinity tolerances were found, but higher population values per buoy were needed to make reliable statements about most species.

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Biofouling Organisms and Their Salinity Tolerance On Navigational Buoys in Upper San Francisco Bay

by

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Lieutenant, United States Coast Guard
B.S., United States Coast Guard Academy, 1973

Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

The navigational buoys situated along the main shipping channel of San Francisco Bay's upper portions - through San Pablo and Suisun Bays - provide biofouling surfaces of constant depth with known maintenance histories and fixed locations through a mean salinity range of 4 to 24 parts per thousand (ppt). Investigation of the biofoulers of these buoys indicates the typical communities and which species are salinity constrained in range and by what salinity. Twelve sets of samples were taken, each consisting of the surface scrapings of two 929 square centimeter (cm) (one square foot) areas, one with its top margin at the mean waterline, the other with its upper margin at the 61 cm depth level. This was done (with a few exceptions) resulting in 23 individual samples being obtained with 41 species identified and 48,376 individual organisms counted. San Pablo Bay's dominant biofouler is the mussel *Mytilus edulis* growing in heavy colonies with worms, amphipods, tunicates, and bryozoans. Suisun Bay's biofouling growth is of three parts - algal from the surface to 15 cm depth; a low biomass of barnacles and amphipods to a depth of 61 cm; and thereafter the erect bryozoan *Membranipora perfragilis* dominates. In San Pablo Bay, the barnacle *Balanus crenatus* is replaced by *Balanus improvisus* at salinities of less than 21 ppt. Some less well defined salinity tolerances were found but higher population values per buoy were needed to make reliable statements about most species.

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I. INTRODUCTION

This thesis is a result of an interest in what, if any, easily identified biofouling species may be of value as "salinity indicators" by virtue of the maximum or minimum salinity tolerances within which that species may be found. The opportunity to gather the necessary raw data presented itself through U. S. Coast Guard contacts and so resulted in a study of the salinity tolerances of the biofoulers of navigational buoys along the main shipping channel of San Pablo and Suisun Bays. The only previous study was a survey made in 1942 of the fouling of navigational buoys in San Francisco Bay which was reported in Marine Fouling and Its Prevention, prepared by Woods Hole Oceanographic Institution for the U. S. Navy during and after World War II.

The author's most sincere appreciation must be extended to the commanding officer and crew of the U. S. C. G. C. Blackhaw without whose aid the raw data would never have been gathered. The assistance and information provided by them and the other coastguardsmen of San Francisco station were of great value.

Invaluable aid in classification of various species was given in a professional and rapid manner by many people, among them: Dr. I. A. Abbott of Hopkins Marine Station, J. T. Carlton of University of California at Davis, Dr. E. C. Haderlie of the U. S. Naval Postgraduate School, L. Holberg of Moss Landing State Marine Laboratory, and

J. Inase of San Francisco State University. Their help was irreplaceable and significant to this study.

Finally, the author's wife and friends must be given credit for enormous patience in tolerating formalin fumes and dark mutterings of "critter counting," while providing steady support to him in his endeavors.

II. NATURE OF THE PROBLEM

The study presented in this paper is of two parts. First, the examination of the biofouling community typical of a near-surface hard substrate located in or near the main shipping channel of the northern portions of San Francisco Bay. Second, an attempt to correlate species population trends with the environmental parameters, especially salinity, and to determine some salinity tolerance values where possible when the correlation is strong enough.

Resolving the first part required a sampling of the communities present over a wide area in a relatively short period of time. It also demanded a known history of the substrate including its anti-fouling treatment. This could be satisfied by the services of the U. S. Coast Guard as discussed below.

Solution of the second part required both sufficient population data and accurate environmental data to define the gradients present in the water. This portion of the overall problem proved less amenable to easy resolution, as will be discussed later.

A brief summary of buoy operations is included here to provide the necessary background for the references to it throughout the paper. The U. S. Coast Guard is charged with maintaining "aids to navigation" throughout U.S. navigable waters. As part of this system it uses a system of floating navigational buoys to mark the main shipping channel in the upper San Francisco Bay. To service these buoys there is a buoy overhauling facility at Yerba Buena Island in San Francisco, and a 180 foot long buoytender ship, the U.S.C.G.C. Blackhaw, also at Yerba Buena Island.

One of the functions of the facility is to treat the exteriors of buoys brought in for overhaul in the following manner: sandblasting to smooth clean metal, one coat of wash primer, eight coats of anti-corrosive red lead (nine layers are sometimes necessary to achieve the desired paint thickness under some weather conditions), two coats of standard anti-fouling paint, and two coats of the appropriate color paint. All the paints used are standard types obtained through the U. S. Navy's G.S.A. stock system. After drying, a buoy is placed on piers where it awaits loading onto the buoytender (see Illustration 1 for a recently overhauled and loaded buoy before its immersion in the bay). The time between these major overhauls is a function of how the paint holds up in protecting the metal from corrosion, not how effective it remains in retarding biofouling (Pers. com., Mr. Evans, Shop Foreman, Yerba Buena buoy facility).

The only other maintenance a buoy receives on a regular basis is a "scraping and inspection" every other year by the buoytender. This consists of the buoy being lifted out of the water (at its station in the bay), manually scraped clean of biofoulers with broad flat blades similar to paint scrapers mounted on broom handles, while the light, battery, and condition of the chain are checked. Its maximum exposure time out of water is one half hour at most. The quality of this exterior cleaning is generally very good including removal of barnacles. The elapsed time between freshly painted buoys being placed in the water and being sampled, and the time between the last previous cleaning and sampling for the buoys used in this study is shown in months on Table I.

The buoys of the shallow upper San Francisco Bay reaches were to be replaced by permanently fixed steel pilings in the fall of 1976. This would mean the removal of large numbers of main shipping channel buoys over a relatively short period of time, providing the sampling opportunity required. By riding aboard the U.S.C.G.C. Blackhaw as this was done, sample scrapings of buoy surfaces could be obtained and correlated with the buoy's history, records of which were kept on the ship (Pers. com., Lt. jg. C. Amen, Operations Officer, U.S.C.G.C. Blackhaw).

TABLE I
BUOY DATA

BUOY NUMBER	2A	3a	3b	5	7	8	9	11	12	13	10	14
Time since last painted (mo.)	77.3	43.5	43.7	81.9	67.3	65.2	49.7	65.7	46.3	91.8	35.1	73.8
Time since last scraped clean (mo.)	11.7	12.3	0.2	2.2	6.7	11.7	11.7	4.9	11.7	11.5	4.0	11.5
Depth of water (feet)	25	37	37	36	32	32	30	30	31	38	30	28
Distance to next buoy upriver (nautical miles; "_" indicates cross-channel buoys)	1.7	2.0	-	1.2	0.1	1.2	1.1	0.1	1.1	6.6	0.6	-
Date sampled (mo./day/76)	8/9	8/2	8/9	8/9	8/9	8/9	8/9	8/9	8/9	8/2	8/2	8/2
Order in which sampled	5	1	6	7	9	8	10	11	12	2	4	3
Amount of area sampled (sq. cm. unless indicated by "_" as sq. m.)												
Surface	929	-	929	929	929	929	929	929	929	.25	929	.25
61 cm Level	929	.25	929	929	232	929	929	929	929	232	929	929
Number of species:												
Surface	15	-	5	6	17	11	5	9	7	8	5	9
61 cm Level	22	12	4	10	13	18	14	11	13	17	11	15
Total	26	12	8	12	21	20	16	12	16	19	13	17
Buoy positions:												
Latitude (north)												
degrees	37	38	SAME AS BUOY 3a	38	38	38	38	38	38	38	38	38
minutes	58	00		01	02	02	03	03	03	03	03	03
seconds	53	45		51	30	25	10	23	15	34	55	55
Longitude (west)												
degrees	122	122		122	122	122	122	122	122	122	122	122
minutes	25	24		22	21	21	19	18	18	17	03	02
seconds	04	40		21	03	00	45	20	20	00	05	22

MEAN TIME SINCE LAST PAINTED: 61.8 months
ONE STANDARD DEVIATION: 17.9 months

MEAN TIME SINCE LAST SCRAPED CLEAN: 9.3 months
ONE STANDARD DEVIATION: 4.3 months

MEAN DISTANCE TO NEXT BUOY (not including cross-channel buoys): 1.6 n.m.
ONE STANDARD DEVIATION: 1.9 n.m.

III. AREA OF STUDY

The San Francisco estuary system (Figure 1) consists of the upper, central, and south bay areas. The area from which the buoys were to be removed, and therefore the area of interest, was the upper, or north bay (Figures 2, 3, and 4). It is that portion of the estuary north of San Pablo Straits, consisting of San Pablo and Suisun Bays, the Carquinez Straits separating them, and the various inflow rivers, principally the Sacramento and San Joaquin. The latter two provide over 90 percent of the mean annual river discharge into the entire San Francisco system. Due to this large river inflow, the upper bay is the only part of the system showing a permanent, well defined, strong salinity gradient. Of course this gradient varies in location and strength with the seasonal changes in run-off, by as much as 10 parts per thousand (ppt) at one location in San Pablo Bay. Vertically one finds a gradient in the salinity profile also. During high winter run-off the difference at a location may be as much as 10 ppt between the surface and the bottom although in summer's lower water volume discharge it may drop to five ppt (Conomos and Peterson, 1977).

Considerable work has been done in monitoring this system's parameters by the U. S. Geological Survey (U.S.G.S.) office in Menlo Park, California. The salinity and temperature data provided by them is summarized on Graphs 1 and 2 for their permanent data stations in the area of interest to this study (stations five through 15, as shown on Figures 3 and 4) (Pers. com., Mr. R. Smith, U.S.G.S., Menlo Park, California). This area of interest then is the main shipping channel of the upper bay, usually being the only deep portions of the bay (some of it dredged), and usually the area through which the major volume of discharge current flows. It is bounded on the southern, or more saline, end by San Pablo Strait, and on the northern, fresh water end by Roe Island in mid-Suisun Bay.

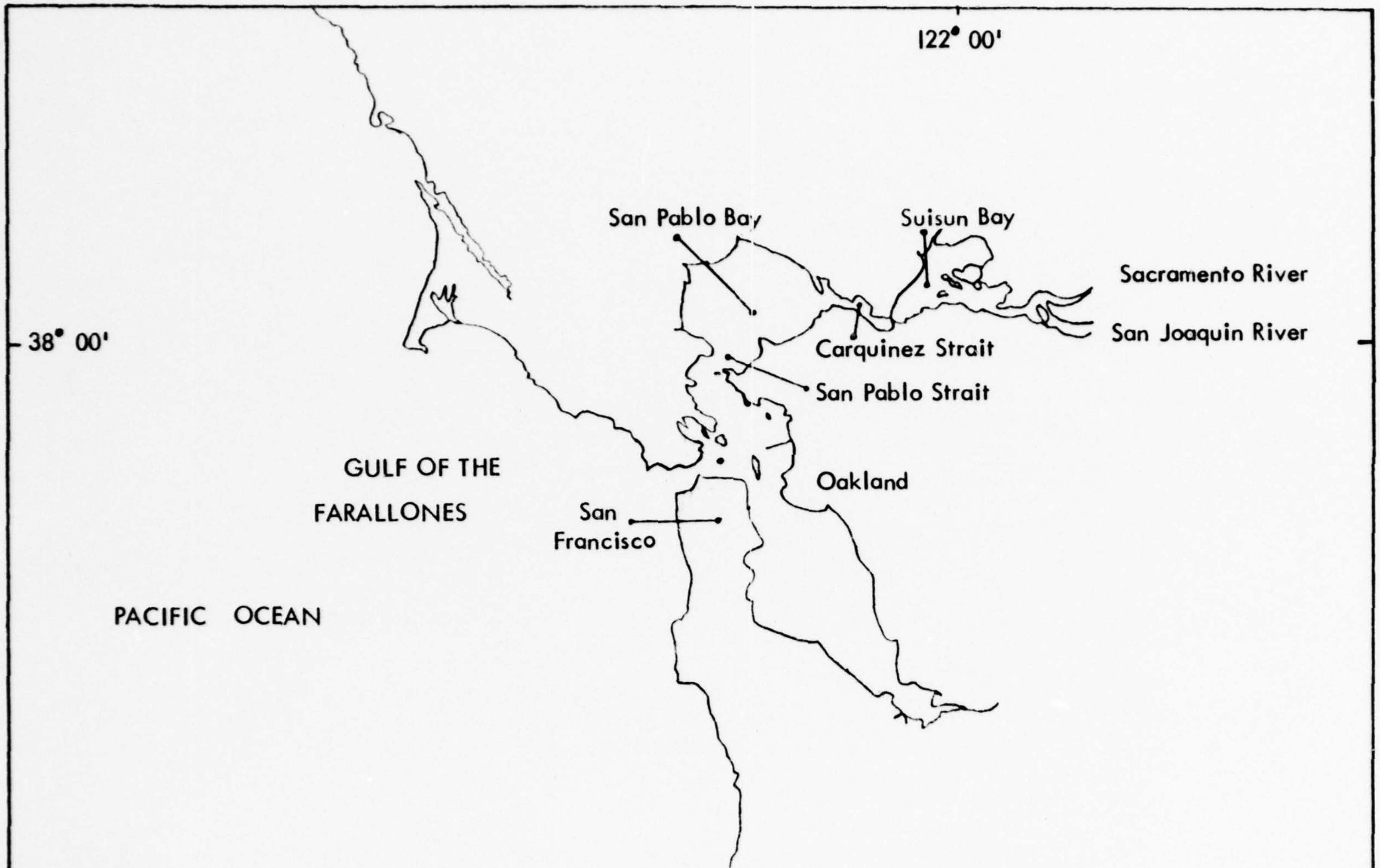


Figure 1. San Francisco Bay. The upper bay is that portion north and east of San Pablo Strait.

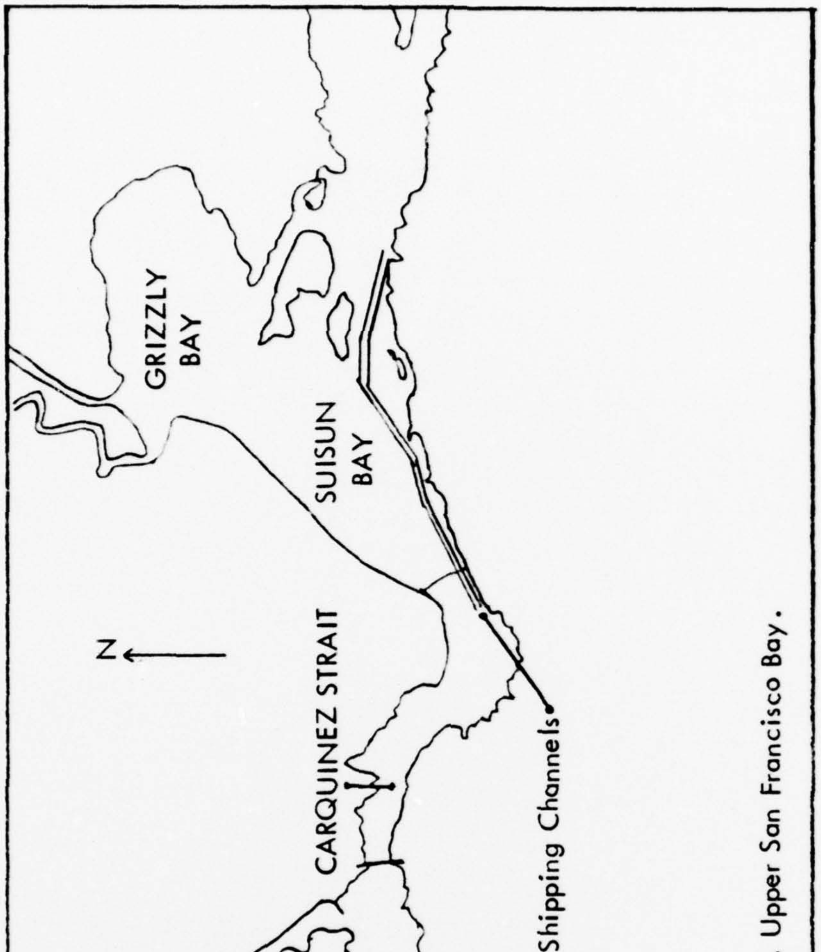


Figure 2. Upper San Francisco Bay.

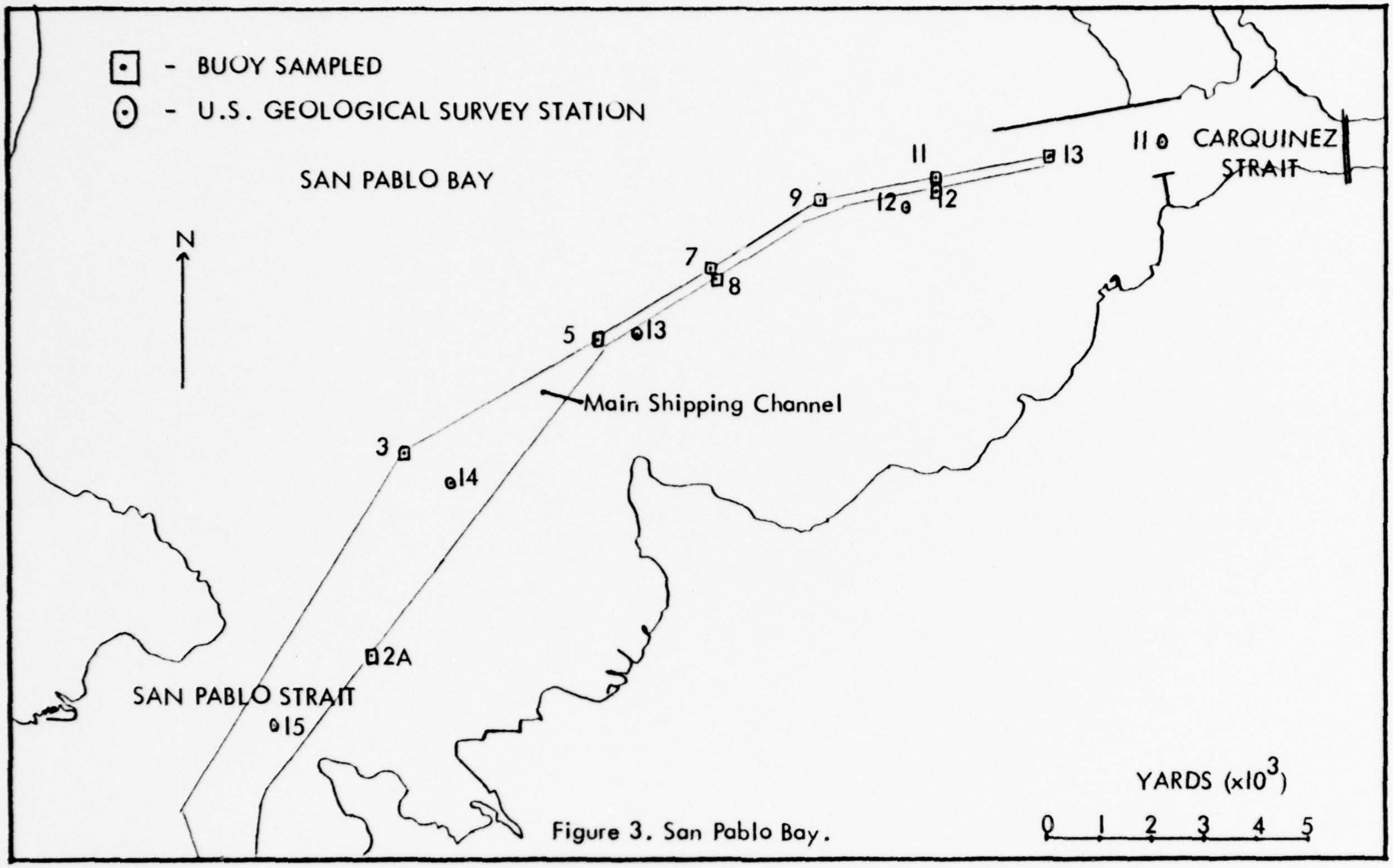


Figure 3. San Pablo Bay.

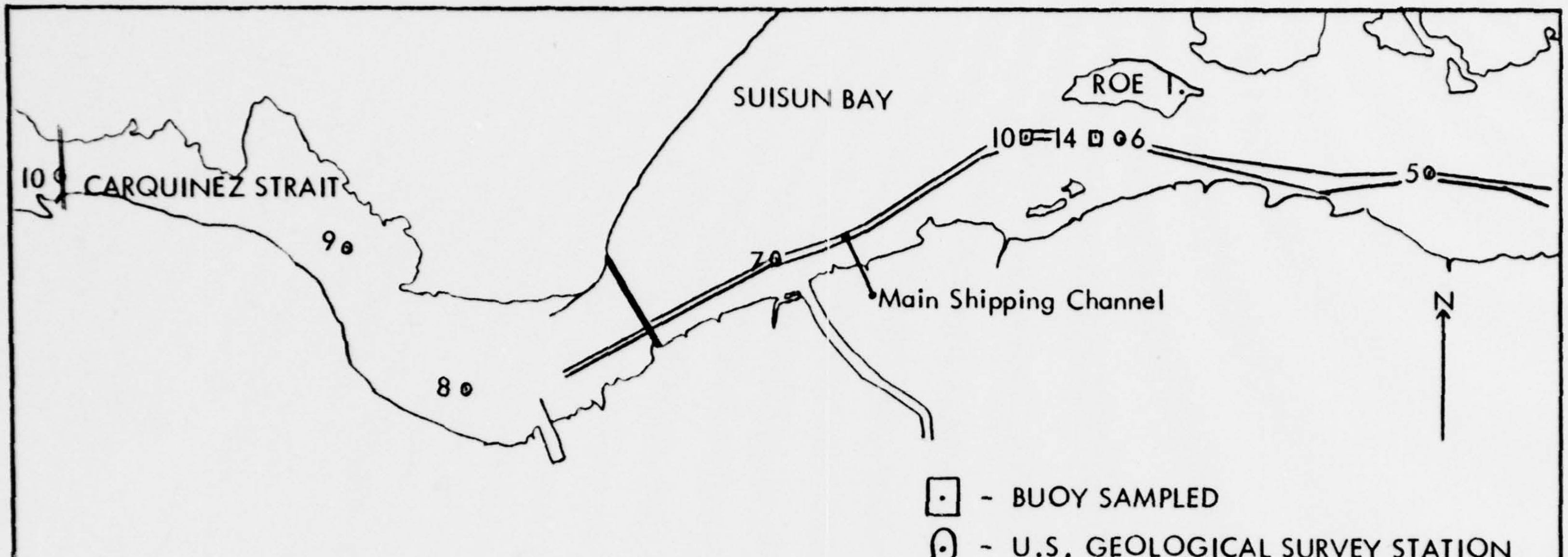
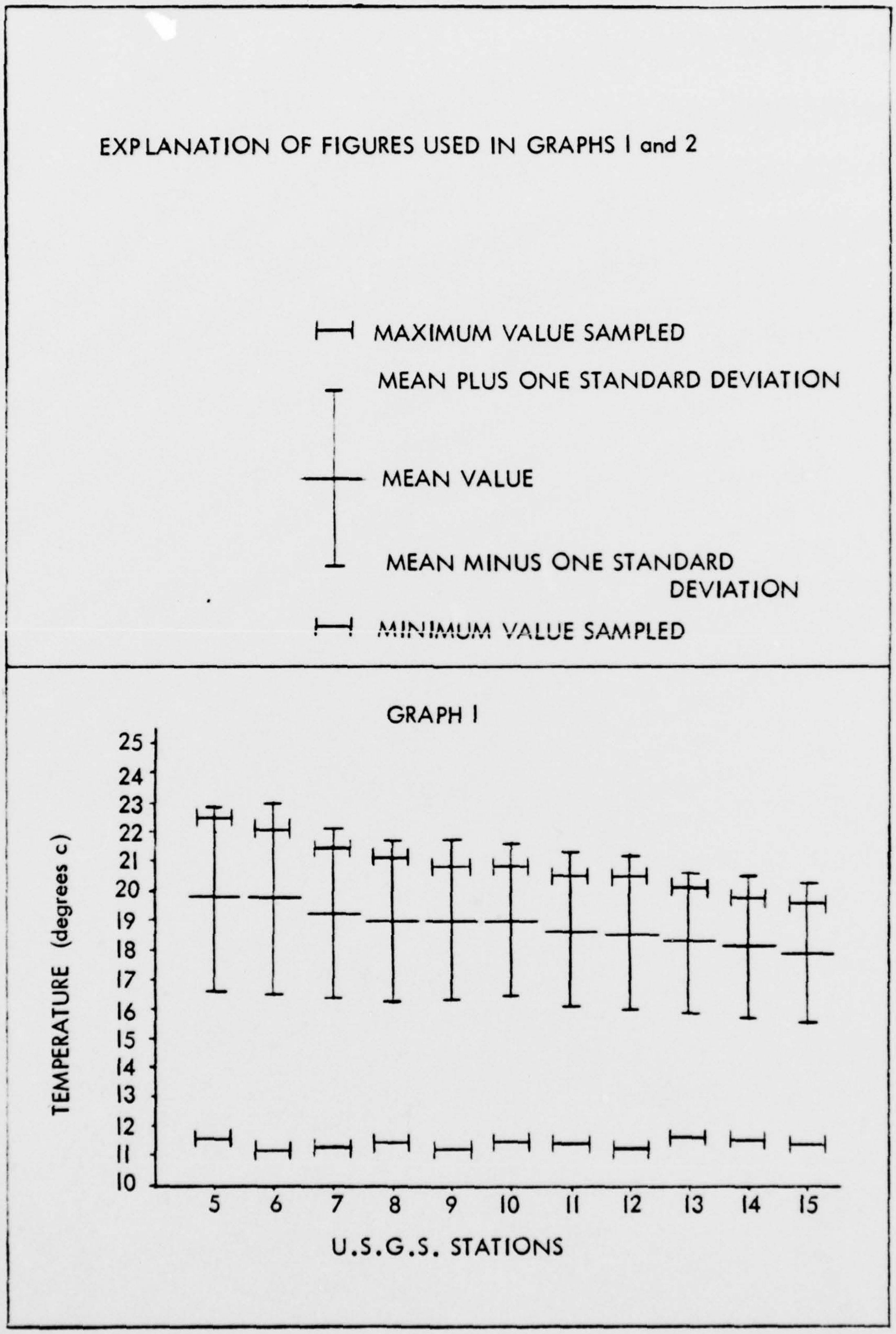
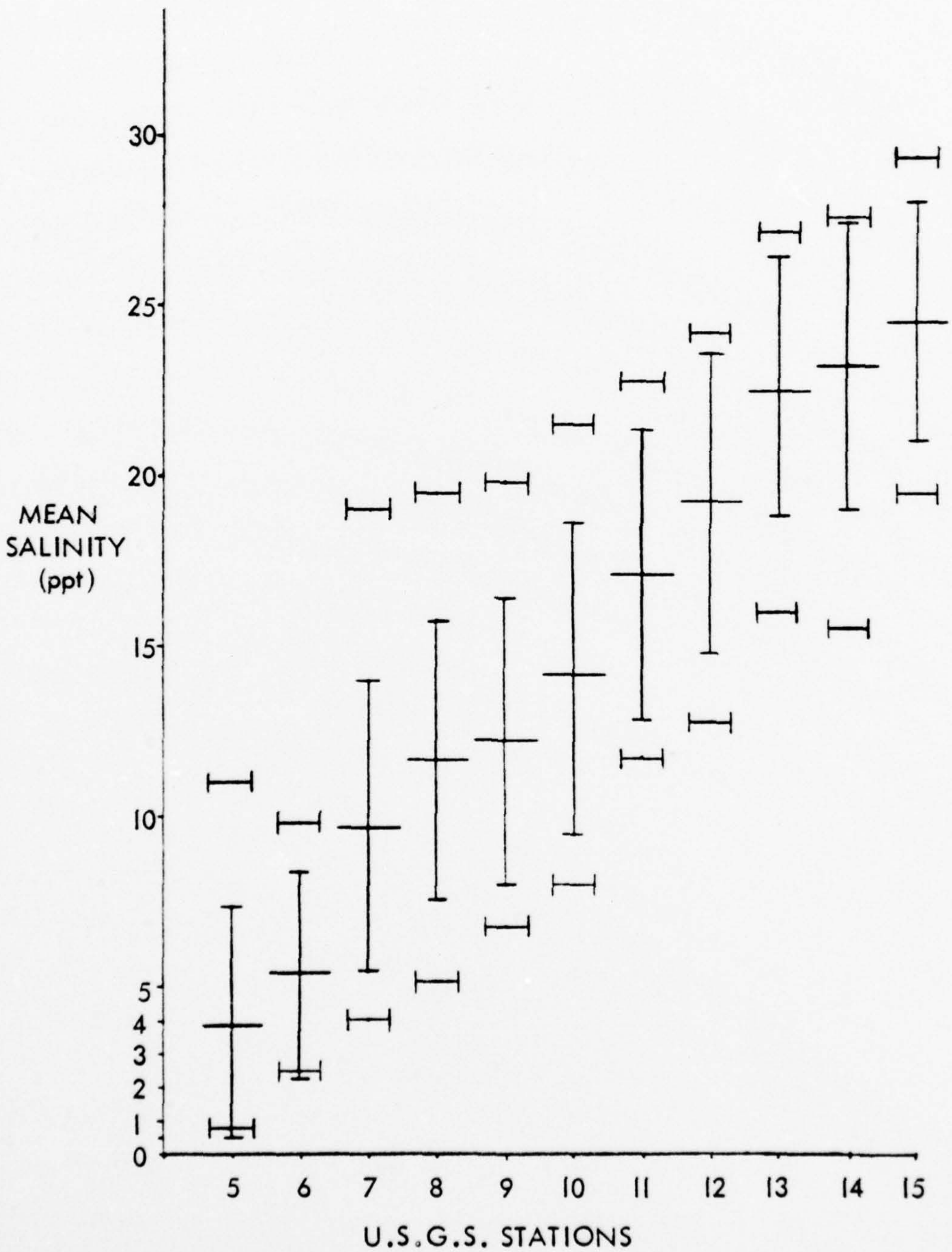


Figure 4. Suisun Bay.


EXPLANATION OF FIGURES USED IN GRAPHS I and 2
MAXIMUM VALUE SAMPLED
MEAN PLUS ONE STANDARD DEVIATION
MEAN VALUE
MEAN MINUS ONE STANDARD DEVIATION
MINIMUM VALUE SAMPLED
GRAPH I
TEMPERATURE (degrees c)
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
5
6
7
8
9
10
11
12
13
14
15
U.S.G.S. STATIONS

GRAPH 2


MEAN
SALINITY
(ppt)
30
25
20
15
10
5
4
3
2
1
0
5
6
7
8
9
10
11
12
13
14
15
U.S.G.S. STATIONS

IV. PROCEDURE

A. THEORETICAL

To analyze both the validity and representativeness of the data obtained, the desired experimental methods should be defined and compared to the sampling technique used. In the process of comparison the assumptions implicit in the sampling methods used must be delineated and their validity judged.

Theoretically one would want the near-impossible following "bill of goods." First the simultaneous identical painting of all the buoys should be done immediately prior to their being put on stations which are evenly distributed along the area of interest. Second they should be scraped clean during routine maintenance at the same time and in a perfectly uniform manner. Third, one would like to sample them all on the same day in the following manner: the surface should be totally cleaned and all fouling organisms collected, this being done in graduated rings one quarter meter wide around the circumference of the buoy, from the waterline to the base. Fourth, a perfect analysis should be made of the samples collected; all organisms should be identified and counted without exception. Fifth and last, the water properties at the buoy locations should be monitored continuously throughout the entire period of interest. Some desired properties would be salinity, oxygen, suspended particles, nutrient levels, pH, and temperature.

B. PRACTICAL

In contrast to the experimental procedure desired, the practical methods used reflect the best acceptable compromise of these goals superimposed on the constraints of real-life limitations. The five idealized requirements will be dealt with in turn, in each case the assumptions and compromises involved will be discussed.

The first assumption required is, though the buoys were painted at different times prior to their being put in the water, that no loss of anti-fouling effectiveness was suffered due to exposure while on land. This can be considered an excellent assumption since the anti-fouling paint was covered with two coats of color paint which would prevent the leeching of toxins, even by rain (therefore "time since last painted" data of Table 1 was figured from elapsed time since the buoy was placed on station in the water, not elapsed time since it was painted). As for regular spacing along the study area - Table 1 and Figures 2, 3, and 4 show that this goal was not as well met (Buoy 7 and 8, and 11 and 12 were "cross-channel buoys," in other words directly across the main channel from each other. Their separation distance was about 0.1 nautical miles, and they were not considered in the following discussion). The mean distance between buoys was 1.6 n.m. with a standard deviation of 1.9 n.m., in other words, a large degree of variability. However if the excessively large distance between San Pablo Bay's Buoy 13 and Suisun Bay's Buoy 10 (due to the Carquinez Straits) is left out of the calculations, the mean becomes 1.3 n.m. with a more acceptable standard deviation of 0.5 n.m. Overall, then this results in a fairly regular coverage of the San Pablo Bay region with a void between the northern end of San Pablo Bay and the middle of Suisun Bay where buoys 10 and 14 are located.

Although this was not done, the effect in terms of antifouling of the buoys having been put on station simultaneously, may be assumed with reasonable certainty. This is due to their accumulated immersion times (i.e., "time since last painted" of Table 1), none of which is less than 35 months. Since the generally accepted effective lifetime of the standard U.S. Navy anti-fouling paint is two years, there should not have been any significant bias due to paint toxins of differing concentrations on different buoys (Pers. com., Dr. E. C. Haderlie, Naval Postgraduate School, Monterey, California). The operative factor is rather the time since the buoy was last pulled out of the water for cleaning. Table 1 shows that all but five buoys have an elapsed time of very close to one year since being scraped clean (exceptions being Buoys 3b, 5, 7, 11, and 10). Therefore the requirement that the buoys were put on station and last cleaned simultaneously can be said to have been fairly well met, with the exceptions noted above. In terms of effective data points throughout the area one should note that Buoys 7 and 11 are cross-channel buoys from other buoys which are very close to the one year mark, so they do not provide a gap in the data grid. Buoy 3b is just a re-sampling of Buoy 3a which was also on the one year time mark since being cleaned. Only Buoys 5 and 10 are a problem then in satisfying this requirement. The mean time since last cleaning and standard deviation values of Table 1 are for all the buoys, but if they are refigured without the above five buoys the more satisfactory result is a mean value of 12.0 months and a standard deviation of only 0.9 months. Of additional value is the fact that samples from Buoys 7, 11, and 3b are at the same salinity points as are one year Buoys 8, 12, and 3a, so that a measure of recolonization rates may be obtained following being scraped clean.

The desired objective of having the buoys sampled simultaneously was also well satisfied due to the mass removal of buoys when the whole series of previously discussed pilings was in place and activated. The U.S.C.G.C. Blackhaw on August 2, 9, and 10, 1976, removed almost all the navigational buoys of the upper bay, permitting relatively large numbers of samples to be obtained over a short time period (23 samples in two 12 hour periods, seven days apart). The one week separation between sampling periods may be considered negligible in light of a one year period for the biofouling growth to accumulate.

Also third on the list of idealized requirements was the specific methods of collecting the organisms from the buoy surface. It was simply not possible to scrape the entire surface of the buoy and retain all the organisms on it; this was even less possible for narrow bands from the waterline down. The next best solution would be to take samples of uniform area, at uniform locations on the buoys, and to a great degree this is what was done. Two samples were collected from each buoy (except for Buoy 3a, the first one done and a "methods testing" case), each was 929 square cm, with bottom and top edges of the square parallel to the waterline of the buoy. A surface sample was taken so that the top edge of the 929 square cm area just encompassed the upper limits of algae growth, coinciding with the buoy's waterline. The other sample was obtained by moving directly down the buoy from the surface sample location and aligning the sample area's top edge with a depth 61 cm below the waterline. The buoys were checked visually for bias growth due to current effects, but none was observed and so any representative point along the diameter was chosen for the surface sample and this then fixed the 61 cm level sample's position also. The actual collection of organisms from the sample area was made rather crudely with the buoy on deck and out of the water no more than five minutes. A paint scraper was used to clean an area into a hand, then the organisms were cleaned from the hand into a clear plastic bag, which was sealed with wire after being filled with 40 percent formalin diluted 1:10 with water.

As detailed in Table 1, the first three buoys to be sampled were not uniformly scraped with respect to area. This was a result of the initial desire to sample an area of one quarter square meter vice 929 square cm (one square foot). The larger area would have been better in terms of getting a more representative collection of species and larger populations of each one. Unfortunately, the plastic bags used were too small to hold a quarter square meter area's biomass and too few bags were available to devote several to each sample. This is what required a reduction of sample area to 929 cm and, even more so, a further reduction to 232 square cm for two buoys (Buoys 7 and 13) due to the extra-heavy mussel colony growth on them. This proved to be a key compromise and a real problem in looking at species population trends. It also required multiplication by appropriate numerical constants to correct number of individuals per buoy figures used for each species on Tables 2, 3, and 4 to 929 square cm equivalent values for Buoys 3a, 13, 14, and 7. How much of an effect this had is hard to determine, although looking at the "numbers of species per buoy" values on Table 1 suggests that it was not significant. The overall reduction in the standard sample area is a serious problem and will be discussed at length later.

Another desired parameter was error-free analysis of the sample once obtained. All microscope work was done with a Bausch and Lomb binocular microscope within the magnification range of 7x to 30x. This limited the study to the larger mult-cellar organisms, with the amphipods being about the smallest size it was possible to identify without aid from an outside source. A point in favor of the accuracy of the analysis is that all the population values were obtained by one investigator minimizing error due to different methods of counting. Identification of algae and smaller species (bryozoans, some worms, and molluscs) was done as needed with the aid of experts, as noted in the introduction.

Finally, a total monitoring of the environment of the upper bay was required to have an accurate data base from which to relate the bio-fouler's distribution, and thereby deduce which species show some salinity tolerance limits and what they are. The only data available to this researcher for the one year period immediately prior to August, 1976, was the U.S.G.S. information summarized on Graphs 1 and 2. It was felt that data for that period only, and not averages from previous years, should be used since the recent two year drought has drastically altered the river discharge levels. The U.S.G.S. was not monitoring these stations on a regular basis through this period, but rather when necessary during occurrence of a special project. This resulted in a rather irregular distribution of sampling dates: four in September 1975, two in July 1975, and two in July 1976, out of 11 total sets of temperature and salinity values. The most noticeable factor is the low variability in temperature suggesting that either salinity or some other unmeasured parameter is responsible for species distribution. It would have provided a more reliable data base to have these values more evenly spaced throughout the year, but the mean values are reasonable and are believed to define well the the gradients of the upper bay during that period.

V. DATA PRESENTATION

A. TABLES

All the tables list the buoys in the following manner: the leftmost buoy is in the most saline, southwesterly end of the study area. To the right of this, progressively, the buoys are ordered in both decreasing salinity and more northeasterly geographical position until the other extreme of the area is reached at Buoy 14 in Suisun Bay. Table 1 sums up in this way the various facts of the buoy histories and geographical positions as obtained from two sources. One was the buoy history records kept on board the U.S.C.G.C. Blackhaw by the Aids-To-Navigation officer, the other was the standard U.S. Coast and Geodetic Survey nautical charts (of which portions were used to form Figures 1, 2, 3, and 4).

Tables 2, 3, and 4 list all species identified and the numbers of each counted per sample (as noted previously, some of these are the result of correction by numerical constants). For both Buoys 7 and 8, Balanus crenatus and Balanus improvisus were so intermixed that no clear determination was possible of how many of each species were present without identifying each individual organism one by one. These counts were denoted by vertical lines bracketing the "numbers of organisms" values, which were themselves staggered between the B. crenatus and B. improvisus lines.

Table 5 lists species for which population trends through the study area could be subjectively discerned. It is divided into three parts; the upper portion shows surface sample species trends based on Table 2. The middle section is for species trends based on Table 3 reflecting the 61 cm level sample populations. The lower portion is from analysis of Table 4, the combined population data of both Tables 2 and 3.

The following system was used to analyze the information in Tables 2, 3, and 4 to arrive at Table 5. First, to eliminate the effects of chance as much as possible (especially on a species with a small total population showing a false trend purely by some accidental distribution of its few organisms), these criteria must be met for the species to be put in Table 5. If it was recorded on Tables 2, 3, and 4 as present/not present (for example, algae), it had to be present on at least two buoys of that table. For a species whose population on each buoy was recorded, it had to be present on at least two buoys, and its total number of individuals on that table must exceed five. Second, general trends in the digit size of populations per buoy were used as much as possible in an attempt to smooth over the variability inherent in the values recorded on Tables 2, 3, and 4 (for example, the trend from a one digit figure to a three digit population per buoy, proceeding upriver, for *Synidotea laticauda* on Table 4). Finally, the point must be made that Table 5 was made up with the geographical distribution of the buoys in mind, especially the significant distance between Buoys 13 and 10; for instance, if higher population values are concentrated throughout Buoys 7 through 13, although they are to the right physically on Table 4, they are in the center of the study area and are included under the "maximum in mid-area" category of Table 5.

Two species fulfilled the above criterion, yet do not fit into any category of Table 5. One is Ceramnium californicum, a red algae was found at either end of the study area but nowhere in between. The other, the "Unidentified nemertean" worms are evenly distributed over the whole area in low numbers (there may be more than one species). Both are from Table 4 and have been left off Table 5.

B. ILLUSTRATIONS

The dominant species of San Pablo Bay was the mussel Mytilus edulis as depicted in Illustrations 2, 3, and 5. This mussel colony growth was most dense on the buoys closest to the southern limits of San Pablo Bay (Illustration 2 versus Illustration 3), and on the buoys that had been in the water since last being cleaned the longest (Illustrations 3 and 5). Supported by this dominant growth were multitudes of worms, amphipods, and isopods with tunicate, bryozoan, and barnacle growth directly on the mussel shells. Caprellids formed an important part of the biofouling community of a newly-immersed buoy until the mussel colony approaches one year of age, at which time the caprellid population drops drastically (correlation of Tables 1 and 3 shows high *Caprella equilibra* and low *Mytilus edulis* populations on buoys with short periods of time since having been cleaned, and the reverse for the buoys having had about a year to develop a mussel colony without it being cleaned off). The mussel colony showed little vertical variation remaining a relatively uniform thickness to within 10 cm of the surface.

The dominant growth of the Suisun Bay buoys appears to be more vertically stratified. Near the surface is a heavy ring of algae, below which, extending for about 30 cm, is a light, low biomass growth consisting mostly of smaller scattered barnacles and amphipods (Illustration 4). Commencing at about 45 to 60 cm below the surface was an increasingly heavier growth of erect bryozoans (*Membranipora perfragilis*) living directly on the surface of a layer of larger barnacles (*Balanus improvisus*). The bryozoan growth was so dense as apparently to block the feeding apparatus of the barnacles, since wherever the bryozoan growth exceeded about 1.5 cm in thickness the barnacles to which it was attached to were dead. Large numbers of isopods and amphipods - with different species dominating than in San Pablo Bay - lived in the bryozoan growth at this depth also.

TABLE 2
SPECIES DISTRIBUTION OF SURFACE SAMPLES

BUOY NUMBER	2A	3a	3b	5	7	8	9	11	12	13	10	14
SPECIES:		NO SAMPLE OBTAINED										
CHRYSOPHYTA												
Colonial diatoms										X		
CHLOROPHYTA												
Enteromorpha intestinalis				X		X		X	X	X		
Ulva lobata	X				X		X	X	X			
Cladophora microcladioides					X						X	
RHODOPHYTA												
Ceramnium californicum												X
Polyneura latissima												
HYDROZOA												
Tubularia crocea												
Obelia sp.												
PLATYHELMINTHES												
Stylochus franciscanus												7
Unidentified TURBELLARIA												
NEMERTEA												
Emplectonema gracile	11				1							
Unidentified nemertean	2				2							
POLYCHAETA												
Halosydna brevisetosa	3				1							
Harmothoe imbricata					2							
Neanthes succina	50		5		38	9		1	4	1		
Unidentified NEREIDAE												
Unidentified polychaete					1							
CIRRIPEDIA												
Balanus crenatus	930		32	62					132			
Balanus improvisus					301	371	141	69		82	121	1
ISOPODA												
Unidentified IDOTEIDAE					1							
Synidotea laticauda												1
Gnorimosphaeroma oregonensis	301		1	19		78				1		1
GAMMARIDEA												
Ampithoe lacertosa	38			317	209	505	559	202	492	104	274	311
Corophium spinicorne	3				3	8		6	1		883	1079
Jassa falcata	26					1		1018				
Parapleustes pugettensis	399		1	1	131	59						
CAPRELLIDEA												
Caprella equilibra	29						1	15				
EUCARIDA												
Cancer sp.												
Hemigrapsus oregonensis												

TABLE 2 (cont.)
SPECIES DISTRIBUTION OF SURFACE SAMPLES

BUOY NUMBER	2A	3a	3b	5	7	8	9	11	12	13	10	14
SPECIES:		NO SAMPLE OBTAINED										
GASTROPODA												
Odostomia (Evalea) sp.												
OPISTHOBRANCHIA												
Okenia plana												
BIVALVIA												
Mytilus edulis	752			1	157	16				1		1
Kellia laperousii												
Mya arenaria												
ECTOPROCTA												
Unidentified CTENOSTOMATA												
Electra crustulenta												
Electra crustulenta arctica												
Membranipora perfragilis												
Hippothoa hyalina												
UROCHORDATA												
Ascidia ceratodes	6				19							
INSECTA												
Unidentified larva	64		5	176	10	80	164	73	67	73	22	45

TABLE 3
SPECIES DISTRIBUTION OF 61 CM DEPTH SAMPLES

BUOY NUMBER	2A	3a	3b	5	7	8	9	11	12	13	10	14
SPECIES:												
CHRYSOPHYTA												
Colonial diatoms		X										
CHLOROPHYTA												
Enteromorpha intestinalis							X	X				
Ulva lobata												
Cladophora microcladioides												
RHODOPHYTA												
Ceramnium californicum	X	X										
Polyneura latissima	X											
HYDROZOA												
Tubularia crocea	X			X								
Obelia sp.		X				X				X	X	X
PLATYHELMINTHES												
Stylochus franciscanus	3				4	1	3		3	8		29
Unidentified TURBELLARIA								1				3
NEMERTEA												
Emplectonema gracile												
Unidentified nemertean						1						3
POLYCHAETA												
Halosydna brevisetosa	2	1					1					
Harmothoe imbricata	41				72	12	27			28		
Neanthes succina	17	1		8	84	30	39	34	23	36	6	3
Unidentified NEREIDAE										20		
Unidentified polychaete												
CIRRIPEDIA												
Balanus crenatus	876	9	6	88	1300	591						
Balanus improvisus							918	733	392	848	40	1711
ISOPODA												
Unidentified IDOTEIDAE												
Synidotea laticauda									1	4	19	180
Gnorimosphaeroma oregonensis	143	9		42	36	229	166	24	30	384	1	2
GAMMARIDEA												
Ampithoe lacertosa	4	2	4	54	20	94	551	87	478	36	261	830
Corophium spinicorne	8	4	8	11	12	6	63	208	72	4	4159	2458
Jassa falcata	2			2		1		380				
Parapleustes pugettensis	16	30		15	344	442	9		55	36	94	142
CAPRELLIDEA												
Caprella equilibra	1883	603	67	4854		11	36	3827	1			
EUCARIDA												
Cancer sp.	1											
Hemigrapsus oregonensis											4	10

TABLE 3 (cont.)
SPECIES DISTRIBUTION OF 61 CM DEPTH SAMPLES

BUOY NUMBER	2A	3a	3b	5	7	8	9	11	12	13	10	14
SPECIES:												
GASTROPODA												
Odostomia (Evalea) sp.	2				4	7						
OPISTHOBRANCHIA												
Okenia plana						1				16		22
BIVALVIA												
Mytilus edulis	556	16		64	1624	513	406	77	134	680	3	10
Kellia lapercusii	1											
Mya arenaria										4		
ECTOPROCTA												
Unidentified CTENOSTOMATA	X											
Electra crustulenta					X							
Electra crustulenta arctica	X					X	X		X	X		
Membranipora perfragilis											X	X
Hippothoa hyalina	X											
UROCHORDATA												
Ascidia ceratodes	9				844	194	164		43	156		
INSECTA												
Unidentified larva						3		9	1	4		

TABLE 4
TOTAL SPECIES DISTRIBUTION OF SAMPLES

BUOY NUMBER	2A	3a	3b	5	7	8	9	11	12	13	10	14
SPECIES:												
CHRYSOPHYTA												
Colonial diatoms		X								X		
CHLOROPHYTA												
Enteromorpha intestinalis				X		X	X	X	X	X		
Ulva lobata	X				X		X	X	X			
Cladophora microcladioides					X						X	
RHODOPHYTA												
Ceramnium californicum	X	X										X
Polyneura latissima	X											
HYDROZOA												
Tubularia crocea	X			X								
Obelia sp.		X				X				X	X	X
PLATYHELMINTHES												
Stylochus franciscanus	3				4	1	3		3	8		36
Unidentified TURBELLARIA								1				3
NEMERTEA												
Emplectonema gracile	11				1							
Unidentified nemertean	2				2	1						3
POLYCHAETA												
Halosydna brevisetosa	5	1			1		1					
Harmothoe imbricata	41				74	12	27			28		
Neanthes succina	67	1	5	8	122	39	39	35	27	37	6	3
Unidentified NEREIDAE										20		
Unidentified polychaete					1							
CIRRIPEDIA												
Balanus crenatus	1806	9	38	150	1601	962			132			
Balanus improvisus							1059	802	392	930	161	1712
ISOPODA												
Unidentified IDOTEIDAE					1							
Synidotea laticauda									1	4	19	181
Gnorimosphaeroma oregonensis	444	24	1	61	36	307	166	24	30	385	1	3
GAMMARIDEA												
Ampithoe lacertosa	42	2	4	371	229	599	1110	289	970	140	535	1141
Corophium spinicorne	11	4	8	11	15	14	63	214	73	4	5042	3537
Jassa falcata	28			2		2		1398				
Parapleustes pugettensis	415	30	1	16	475	481	9		55	36	94	142
CAPRELLIDEA												
Caprella equilibra	1912	603	67	4854		11	37	3842	1			
EUCARIDA												
Cancer sp.	1											
Hemigrapsus oregonensis											4	10

TABLE 4 (cont.)
TOTAL SPECIES DISTRIBUTION OF SAMPLES

BUOY NUMBER	2A	3a	3b	5	7	8	9	11	12	13	10	14
SPECIES:												
GASTROPODA												
Odostomia (Evalea) sp.	2				4	7						
OPISTHOBRANCHIA												
Okenia plana						1				16		22
BIVALVIA												
Mytilus edulis	1308	16		65	1781	529	406	77	134	681	3	11
Kellia laperousii	1											
Mya arenaria										4		
ECTOPROCTA												
Unidentified CTENOSTOMATA	X											
Electra crustulenta					X							
Electra crustulenta arctica	X					X	X		X	X		
Membranipora perfragilis											X	X
Hippothoa hyalina	X											
UROCHORDATA												
Ascidia ceratodes	15				863	194	164		43	156		
INSECTA												
Unidentified larva	64		5	176	10	83	164	82	68	77	22	45

TABLE 5
POPULATION TRENDS

POPULATION TRENDS	INCREASING IN THE UPRIVER DIRECTION	DECREASING IN THE UPRIVER DIRECTION	MAXIMUM VALUES IN MID-AREA
Surface Samples	Cladophora microcladioides Balanus improvisus Corophium spinicorne	Emplectonema gracile Neanthes succina Balanus crenatus Gnorimosphaeroma oregonensis Parapleustes pugettensis Caprella equilibra Mytilus edulis	Enteromorpha intestinalis Ulva lobata Ampithoe lacertosa Jassa falcata Ascidia ceratodes Unidentified insect larva
61 cm Level Samples	Obelia sp. Stylochus franciscanus Balanus improvisus Synidotea laticauda Ampithoe lacertosa Corophium spinicorne Hemigrapsus oregonensis Okenia plana Membranipora perfragilis	Ceramnium californicum Tubularia crocea Balanus crenatus	Enteromorpha intestinalis Harmothoe imbricata Neanthes succina Gnorimosphaeroma oregonensis Jassa falcata Parapleustes pugettensis Caprella equilibra Odostomia (Evalea) sp. Mytilus edulis Electra crustulenta arctica Ascidia ceratodes Unidentified insect larva
Total Samples	Cladophora microcladioides Obelia sp. Stylochus franciscanus Balanus improvisus Synidotea laticauda Ampithoe lacertosa Corophium spinicorne Hemigrapsus oregonensis Okenia plana Membranipora perfragilis	Colonial diatoms Tubularia crocea Emplectonema gracile Halosydna brevisetosa Balanus crenatus Parapleustes pugettensis Mytilus edulis Electra crustulenta arctica	Enteromorpha intestinalis Ulva lobata Harmothoe imbricata Neanthes succina Gnorimosphaeroma oregonensis Jassa falcata Caprella equilibra Odostomia (Evalea) sp. Ascidia ceratodes Unidentified insect larva

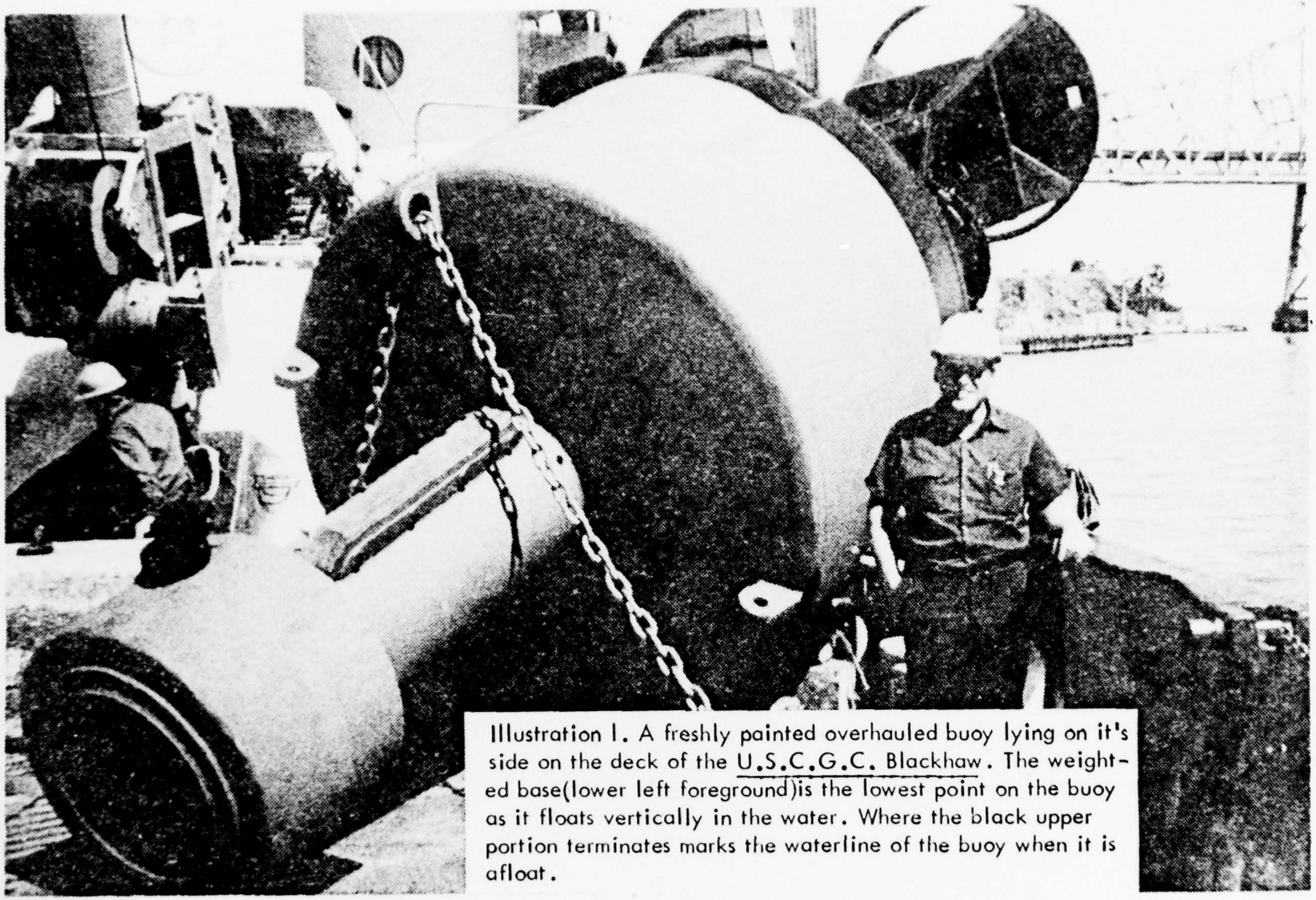


Illustration I. A freshly painted overhauled buoy lying on it's side on the deck of the U.S.C.G.C. Blackhaw. The weighted base(lower left foreground)is the lowest point on the buoy as it floats vertically in the water. Where the black upper portion terminates marks the waterline of the buoy when it is afloat.

Illustration 2. Buoy 2A located in south San Pablo Bay, the most saline end of the study area.

Illustration 3. Buoy 8 located in mid-upper San Pablo Bay, about the middle of the study area.

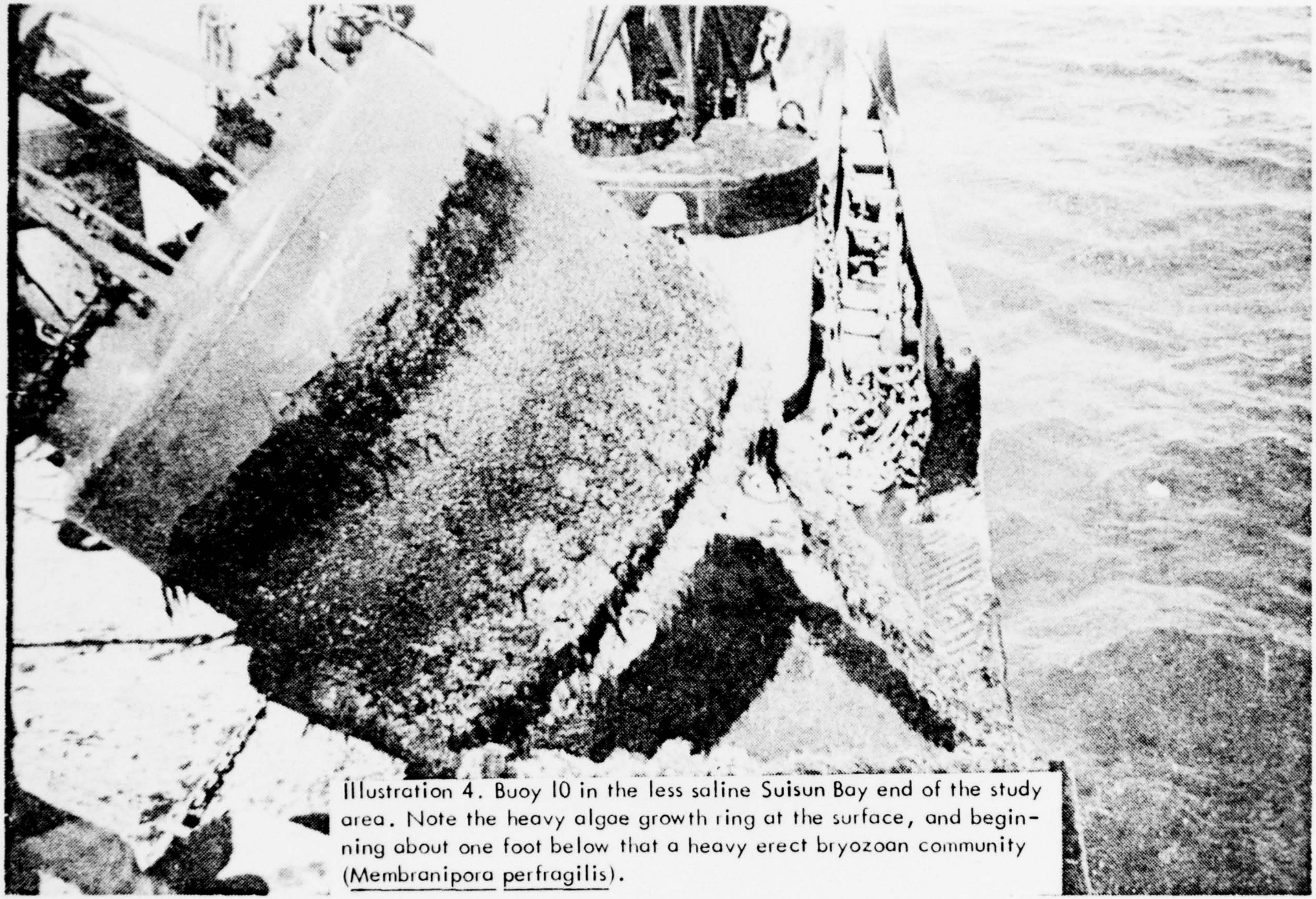


Illustration 4. Buoy 10 in the less saline Suisun Bay end of the study area. Note the heavy algae growth ring at the surface, and beginning about one foot below that a heavy erect bryozoan community (Membranipora perfragilis).

Illustration 5. Buoy 7, last scraped just less than seven months previous to the picture. Compare this to it's cross-channel buoy, Buoy 8(Illustration 3)which had been last scraped clean one year before it was sampled.

Illustration 6. Buoy 5, scraped two months one week prior to the picture being taken .

Illustration 7. Buoy 3b, scraped one week prior to this picture. This is a good example of a cleanly scraped buoy.

VI. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The research accomplished one of its two main objectives. It did in fact examine, identify, count, and record the biofoulers typical of floating hard surfaces in or near the main shipping channel of San Pablo and Suisun Bays and the results are summarized in Tables 2, 3, and 4. The fortuitous sampling in a short period of time of a large number of buoys spanning most of San Pablo and some of Suisun Bays gives a good illustration of the biofouling communities in these environments. The San Pablo Bay community is dominated by the mussel Mytilus edulis, the density of the growth is increased by both increased length of time immersed, and by a more southerly (more saline) location in the bay. Also observed are the tunicate Ascidia ceratodes, the barnacles Balanus crenatus and Balanus improvisus, various worms, amphipods, and encrusting bryozoans. On the other hand, the Suisun Bay buoys showed vertical stratifications in growth with algal rings at the surface, and little below that; then, increasing with depth and beginning about 61 cm below the surface, a colony of the erect bryozoan, Membranipora perfragilis was present up to 4 cm thick. At its thicker portions it appeared to be destroying the surficial barnacle growth upon which it is attached by blocking the barnacle's feeding apparatus.

The other main objective, correlating species population trends with the salinity gradient of the study area, was not very well achieved due to the lack of sufficient population numbers per buoy of many species to really determine their salinity tolerances. One of the most striking and best documented salinity "borders" was the value of 21 ppt for the barnacles *Balanus crenatus* and *Balanus improvisus*. Only *B. crenatus* was found on buoys in higher salinity environments, while *B. improvisus*, with one exception, was the only barnacle found in lower salinity locations. This one exception was not very far upriver from the 21 ppt gradient line, and may indicate a point where eddies or local perturbations of the mean flow may introduce higher salinity water at that point without it being reflected in the U.S.G.S. station data. However, right at 21 ppt, on Buoys 7 and 8 the two species intermingle freely. This may be due to the fact that 21 ppt is just within the survival salinity tolerance for both species; or it may result from neither species, at this salinity, having an edge over the other in adapting to this particular environment. Many other species showed trends to varying degrees, as detailed on Table 5, but not as well defined. To obtain the desired reliable correlation between species and salinity will require more organisms per buoy per species. This in turn requires sampling a larger area than was achieved using the experimental methods of this research project.

B. RECOMMENDATIONS

Two recommendations to future reseachers are submitted. One is to develop a better scraping technique and apply it to uniform areas on all the surfaces to be sampled. Second, either limit the study to fewer buoys and sample larger surface areas, or attempt to include a population trend analysis for only the half dozen numerically most common species.

Further research in the same areas of San Francisco Bay would be of value to confirm or deny the biofouling community profiles determined in this study (especially in years of more normal river discharge patterns). Steel pilings have been located permanently where the buoys at one time were, and one may either sample a large number of them as this study has done, or look very carefully at almost the entire surface of one (or a few) from the waterline to the bottom. Exact information concerning the time and location implanted, and antifouling treatment used, if any, for the underwater portions may be obtained from the U.S. Coast Guard in San Francisco. Salinity and temperature parameters for that portion of the bay may be obtained from the U.S. Geological Survey in Menlo Park, California. To obtain more regularly scheduled data, a researcher may wish to gather his own data at the pilings. This could be done in two ways; either way is rather expensive. One way would be to attach a set of measuring and recording (or transmitting) gear to each platform (this would require permission of the U.S. Coast

Guard). The other way would be to mount this gear in a boat, as the U.S.G.S. has done, and to cruise a set of standard stations on a regular basis.

Other types of buoy biofouling study suggest themselves such as a study of the three offshore "monster buoys" used in place of lightships off the California coast. One of the three is brought in each year to San Francisco for overhaul and drydocking, offering a large (20 meters in diameter) surface area with three years worth of dense biofouling growth which was at a known location for a known period of time. Another study possibility would be a sampling of the near-shore oceanic conventional buoys (such as the one off Pt. Pinos, Monterey) in a north-south survey (one buoytender based in San Francisco services all the buoys between Morro Bay and the California-Oregon border).

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